Construction Of An Efficient PIPS Model With An Accurate Plastic Solution For Sea Ice Dynamics

Jinlun Zhang
Polar Science Center, Applied Physics Laboratory
University of Washington
Seattle, WA 98105-6698
Phone: (206) 543-5569; Fax: (206) 616-3142; email: zhang@apl.washington.edu
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LONG-TERM GOALS

Our long-term goals are to develop and implement lead-based sea ice rheologies into a high-resolution multi-category thickness distribution sea ice model that is able to efficiently simulate and predict the initialization and propagation of leads and ridges of sea ice. Our particular interest is to provide such a lead-resolving thickness distribution sea ice model for the Navy's Polar Ice Prediction System (PIPS) for high-resolution large-scale sea ice forecasting. We are also interested in using the model to study the dynamic and thermodynamic sea ice processes that trigger leads and ridges to form and propagate in time and space in relation to atmospheric and oceanic forcing.

OBJECTIVES

The Navy's next-generation sea ice model, PIPS 3.0, aims at high-resolution (9-10 km), lead-resolving forecasts of sea ice and ambient noise in most ice-covered regions in the northern hemisphere. To help PIPS to meet such a goal, our task is to develop a new numerical model for sea ice dynamics and give the model to the PIPS model development group at the Naval Postgraduate School. In order to conduct high-resolution, lead-resolving forecasts, this model must be numerically efficient in solving sea ice momentum equations. It must also be able to obtain an accurate plastic solution for ice motion, stress, and deformation, governed by a viscous plastic sea ice rheology (Hibler, 1979). This is because an accurate plastic solution is essential for successfully predicting leads and ridges.

APPROACH

Our approach is to use the numerical method newly developed by Zhang and Rothrock (1999) to solve sea ice momentum equations. This method is based on an alternating direction implicit (ADI) numerical technique. This technique has been widely used in numerically solving mathematical and engineering problems (Fletcher, 1988) in other fields. It has been used by Zhang and Rothrock (1999) for the first time, to solve for sea ice dynamics. This numerical model for sea ice dynamics has been found to be efficient and accurate in obtaining a plastic solution for ice motion, stress, and deformation. Therefore it is desirable to be used in PIPS.

WORK COMPLETED

Given that PIPS 3.0 will be based on a rotated spherical coordinate system, we have converted the ADI numerical model from the original rectangular coordinate system into a rotated spherical coordinate

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system. The model has been coded following the spherical-coordinate formulation provided by Zhang and Hibler (1997), which includes all the metric terms in the sea ice momentum equations. The ADI model for sea ice dynamics has been provided for the PIPS model development group, lead by Dr. A. Semtner, at the Naval Postgraduate School.

In order to make certain that the ADI model works satisfactorily with the 9-10 km resolution that is to be adopted in PIPS 3.0, we have conducted a series of numerical tests using a 10-km resolution sea ice model incorporating the ADI procedure. These tests aimed at examining the numerical behavior of a high-resolution ADI model in simulating sea ice of different strengths. For it to be useful for PIPS, the ADI dynamics model must approach an accurate plastic solution efficiently and stably with a 9-10 km model resolution.

RESULTS

From a series of numerical tests, we found that, with a 10 km model resolution, the ADI numerical procedure is still more efficient than numerical procedures that have been commonly used to solve sea ice momentum equations with a viscous plastic sea ice rheology, such as the line successive relaxation procedure (Zhang and Hibler, 1997) and the point successive relaxation procedure (Hibler, 1979). We also found that with such a fine resolution the ADI model is still able to obtain an accurate viscous plastic solution, as shown in Figure 1.

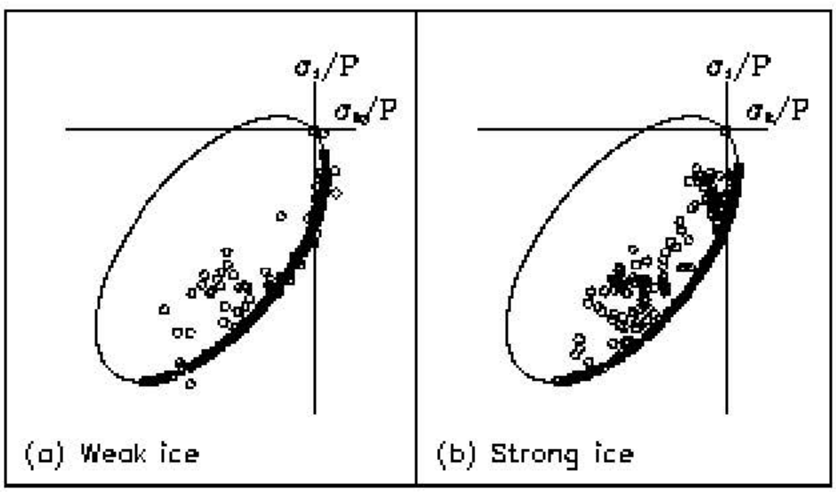

Figure 1. Principal ice internal stress states normalized by ice strength that were predicted using the ADI ice dynamics model with a 10 km model resolution. This figure shows that the model basically obtains an accurate viscous plastic solution in simulating sea ice of different strengths. Most of the stress states fall on the elliptical plastic yield curve, indicating that the ice is in a state of plastic flow. Some of the stress states fall inside the yield curve, indicating that the ice is in a state of viscous flow. Note that when ice is weak, more ice is in a plastic state, so more stress points are on the yield curve. When ice is strong, more ice is in a viscous state, so more stress points are inside the yield curve.

IMPACT/APPLICATION

The Polar Ice Prediction System is the Navy's primary operational sea ice forecast system. PIPS 3.0 with the ADI numerical model for sea ice dynamics will significantly enhance its capability of sea ice forecasting. PIPS 3.0 will provide high-resolution information of sea ice conditions to the Navy for their operations in the ice-covered regions in the northern hemisphere. In addition, realistically predicted fields of ice motion, deformation, stress, and energy dissipation by the ADI model will allow a realistic prediction of ambient noise, which is also important to submarine operations.

TRANSITIONS

As mentioned earlier, we have provided the ADI dynamics model for the PIPS model development group at the Naval Postgraduate School. We will actively work with the group to implement the ADI model into PIPS 3.0. We have also provided the ADI model for the NCAR Climate System Model (CSM) for global climate studies. The ADI model, implemented in CSM, has been successful in simulating sea ice on a global scale. In addition, work is under way to implement the ADI model into the global climate model of the Goddard Institute for Space Studies.

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